

Charm and Beauty

Production at the Tevatron



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On behalf of the



and



collaborations

Charmed mesons

b-jets

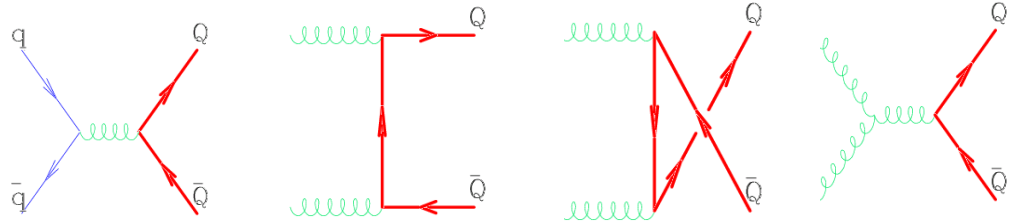
Upsilon and J/ψ production
and back to B-hadrons

focus on

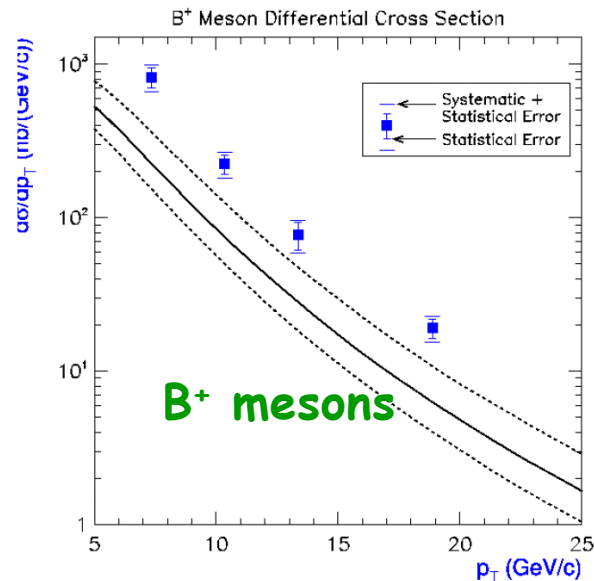
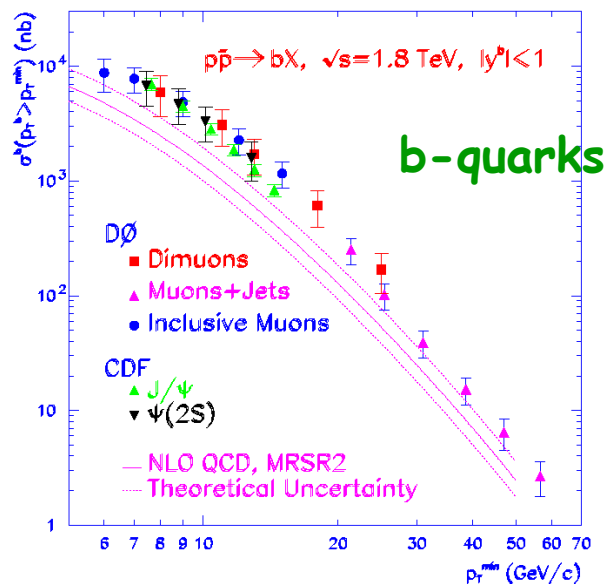
Run 2 data

Since $m_Q \gg \Lambda_{\text{QCD}}$ for c and b quarks, heavy quark production at the Tevatron should be well-calculable in QCD.

Diagrams at leading order:



Full calculations have been done up to NLO (and beyond...)
Therefore Run 1 Tevatron results came as a surprise:



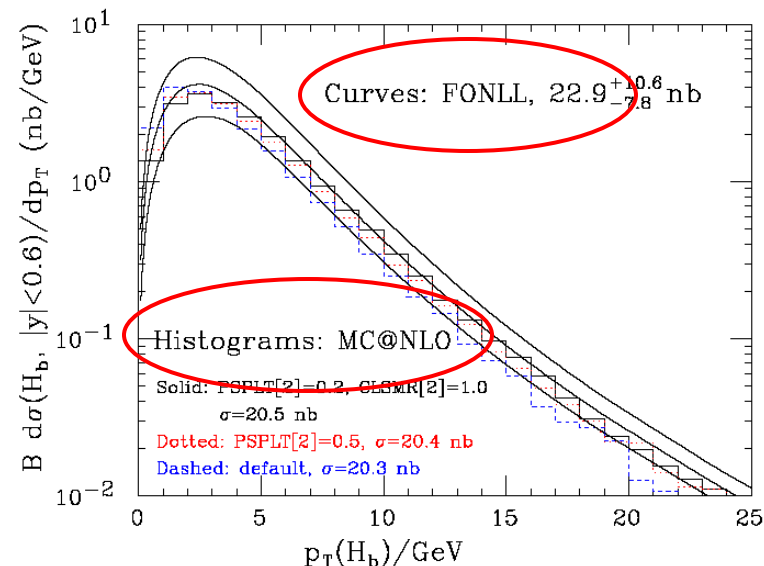
Experiment wrong?

Theory prediction incomplete?

New physics?

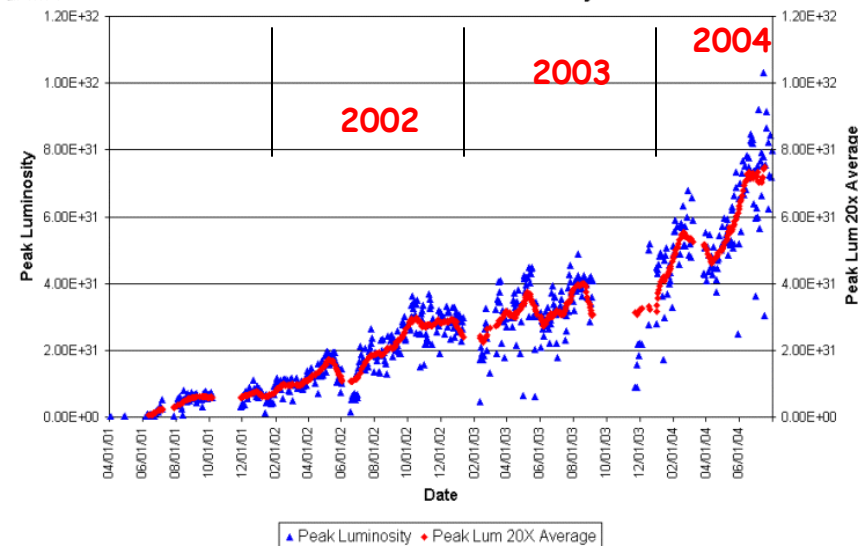
However, in past years many (theoretical) developments:

- Use b-jets rather than b-quarks: less dependent on unfolding and fragmentation uncertainties
- Beyond NLO: resummation of $\log(p_T/m)$ terms \rightarrow FONLL (Cacciari et al). Important for medium/high p_T region
- Extraction of fragmentation function parameters from LEP data in this scheme: substantially different ε_b
- new PDF's
- "Low x" effects? $\text{Log}(\sqrt{s}/m)$ terms. still 20-30% uncertainty?
- light gluino/light sbottom ruled out
- MC@NLO \rightarrow match NLO calculation with PS formalism in HERWIG (Frixione, Nason, Webber)



Keep looking at total cross section, as well as p_T spectrum

Collider Run II Peak Luminosity



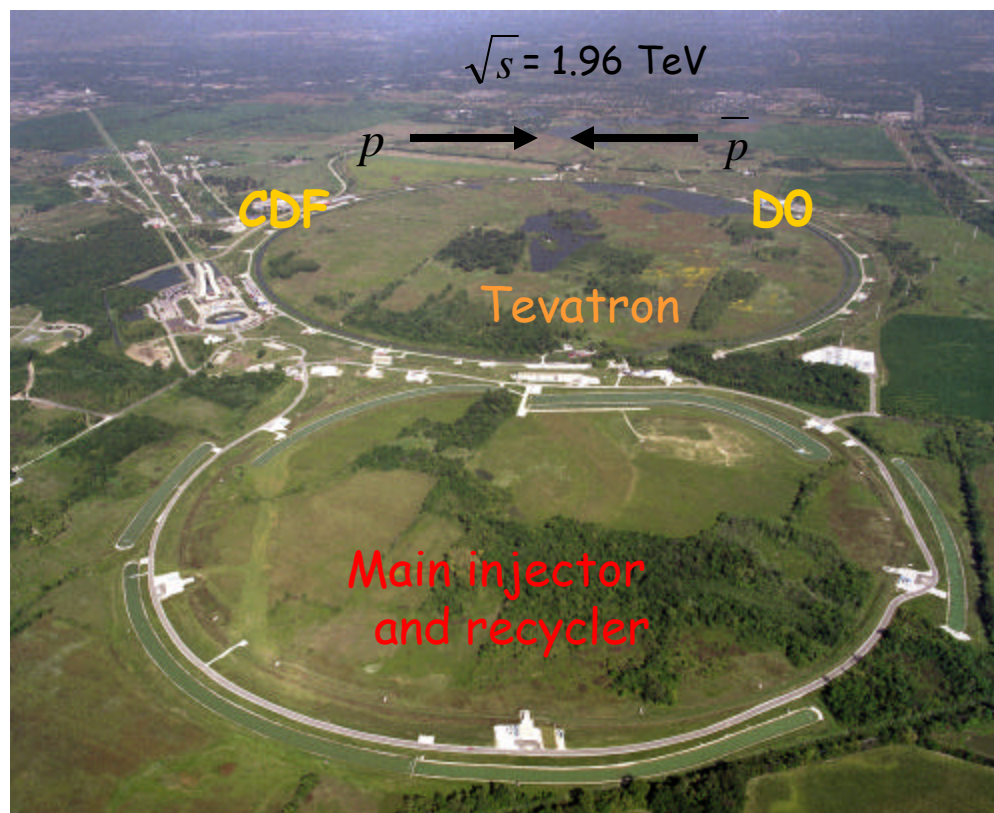
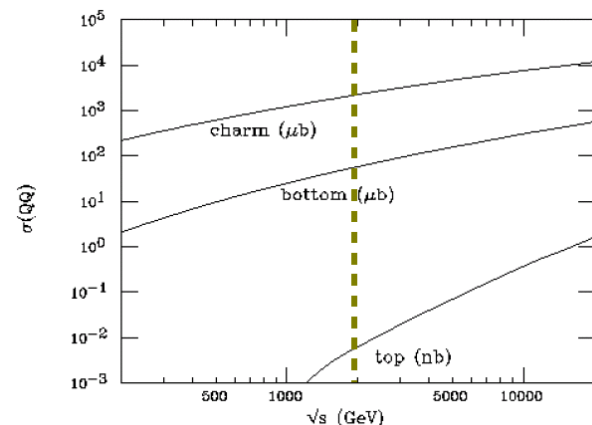
Tevatron peak luminosity is making steady progress, and has exceeded $10^{32} \text{ cm}^{-2}\text{s}^{-1}$

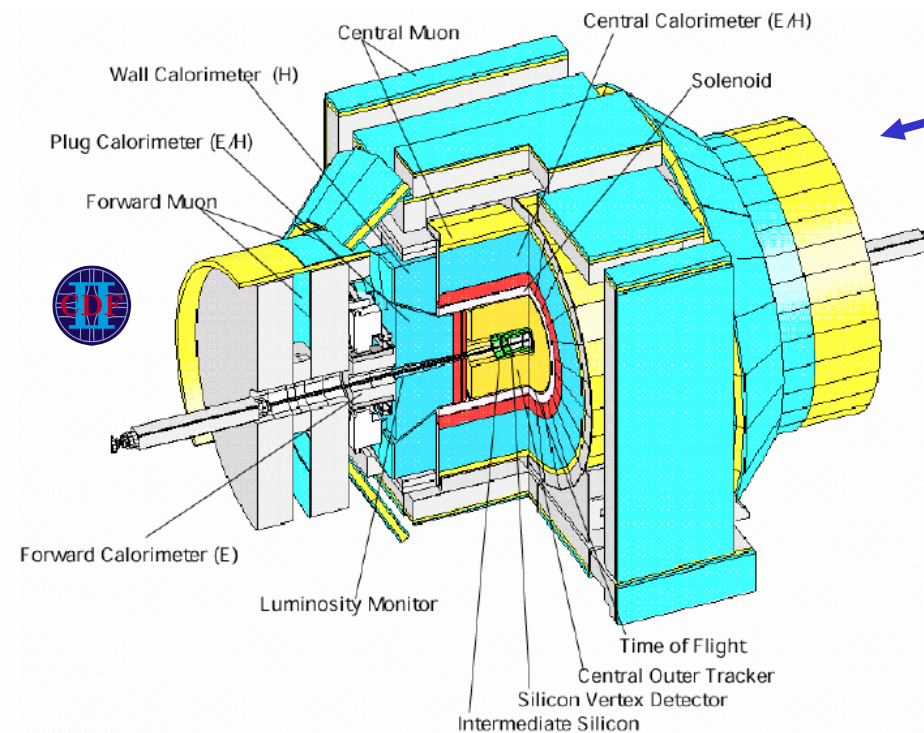
Inclusion of recycler as antiproton storage works → important for even higher luminosities in future.

CDF and D0 have $\sim 400 \text{ pb}^{-1}$ on tape. Analyses shown here use 5-150 pb^{-1}

$\sigma(\text{QQ})$ large, but only tiny fraction of total

↓
trigger is crucial





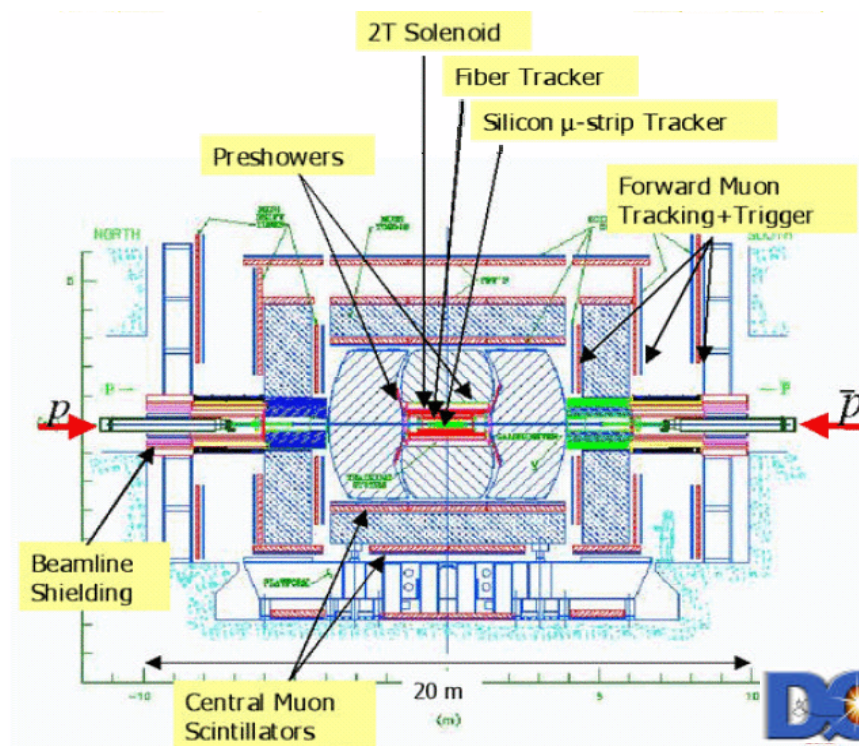
CDF: excellent mass resolution,
particle ID (dE/dx , TOF)

Displaced track trigger has
revolutionized c/b physics:
semileptonic and hadronic modes
L1: fast track trigger
L2: add silicon vertex detector

D0: good muon coverage and
forward tracking
→ high rapidities, high yields

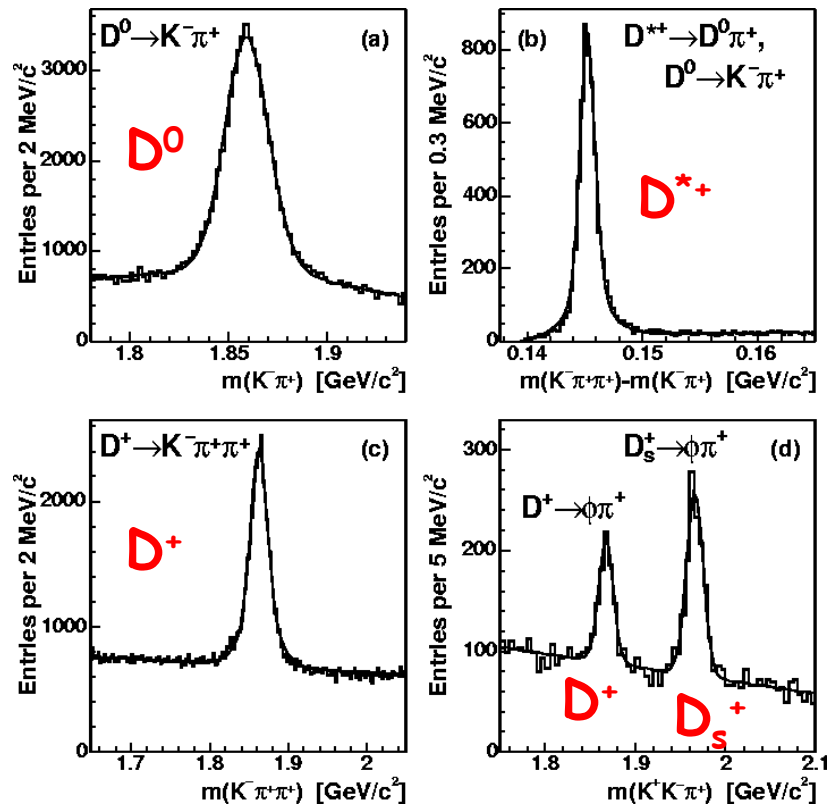
muon trigger: semileptonic modes, J/ψ

Displaced track trigger in final phases
of commissioning

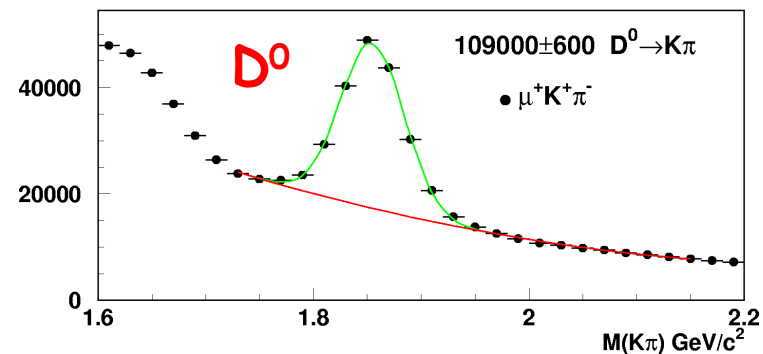


Production of open charm mesons:

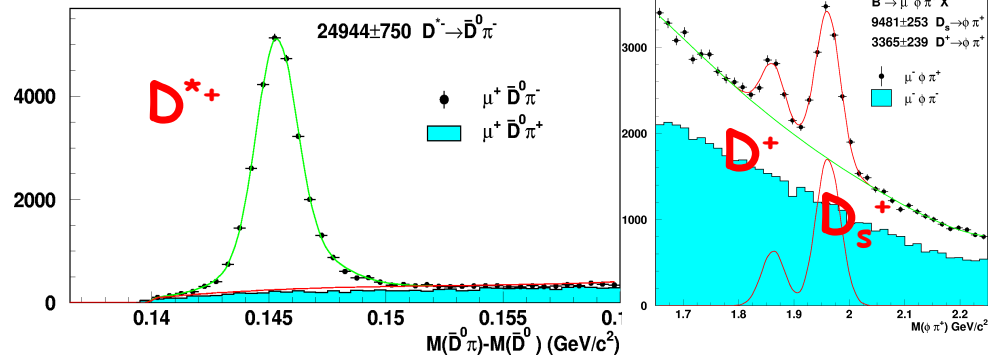
CDF: 5.8 pb^{-1} , taken with displaced track trigger. $>80\%$ prompt production



DØ RunII Preliminary, Luminosity = 250 pb^{-1}

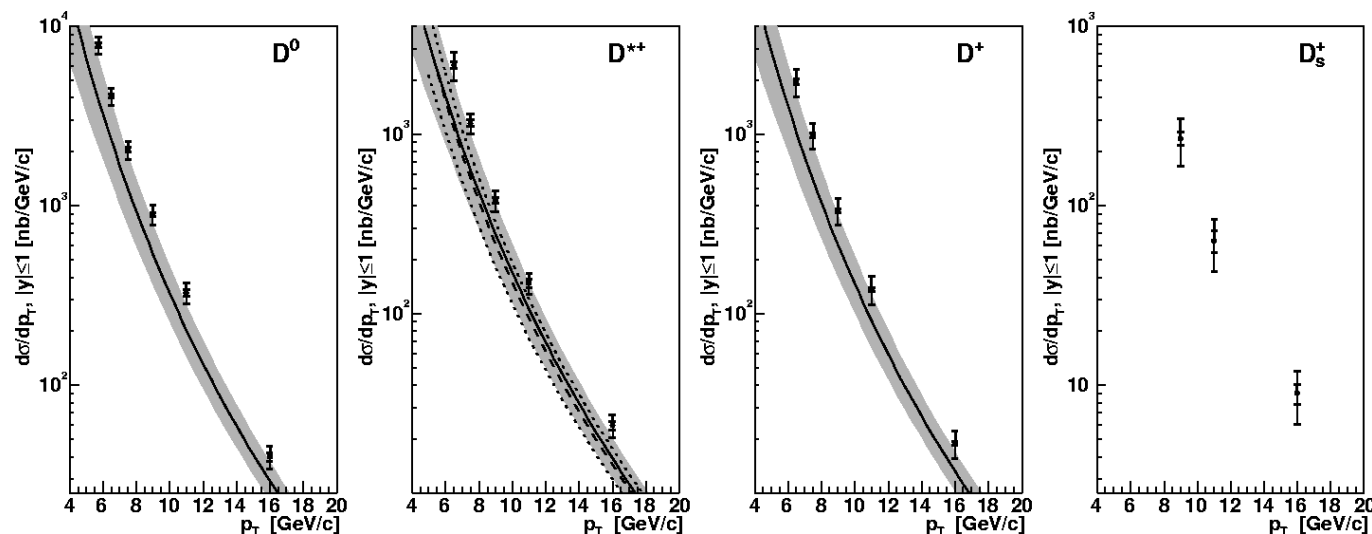
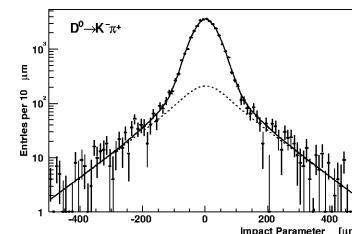


DØ RunII Preliminary, Luminosity = 250 pb^{-1}

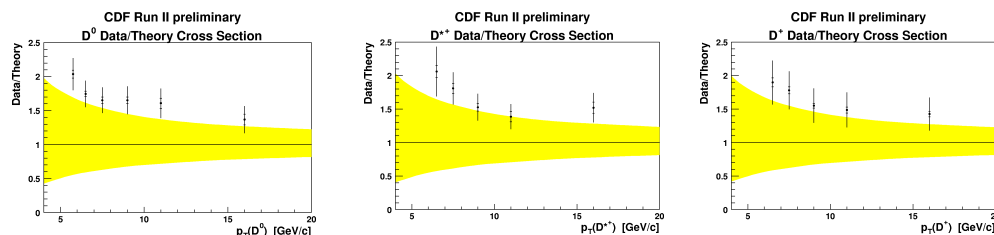


DØ: 250 pb^{-1} , taken with muon trigger. Most D mesons from B decay with associated muon.

CDF: extract prompt charm production component by looking at impact parameter of reconstructed charm meson.
Compare to FONLL theory (Cacciari and Nason):



Prompt fraction:
 D^0 : $86.6 \pm 0.4\%$
 D^{*+} : $88.1 \pm 1.1\%$
 D^+ : $89.1 \pm 0.4\%$
 D_s^+ : $77.3 \pm 3.8\%$
 ($\pm 3-4\%$ syst. err.)

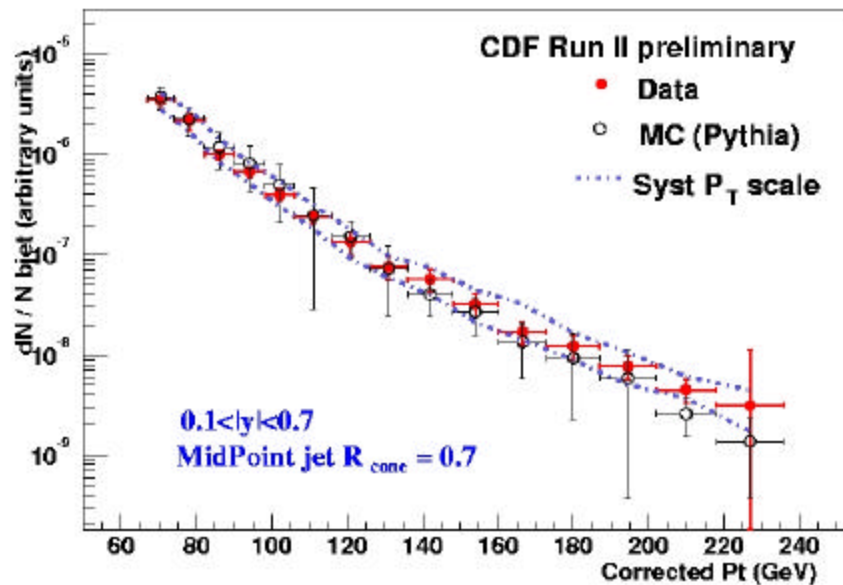


Cross sections for $|y| < 1$:
 $D^0(p_T > 5.5 \text{ GeV})$: $13.3 \pm 1.5 \mu\text{b}$
 $D^{*+}(p_T > 6.0 \text{ GeV})$: $5.2 \pm 0.8 \mu\text{b}$
 $D^+(p_T > 6.0 \text{ GeV})$: $4.3 \pm 0.7 \mu\text{b}$
 $D_s^+(p_T > 8.0 \text{ GeV})$: $0.75 \pm 0.23 \mu\text{b}$

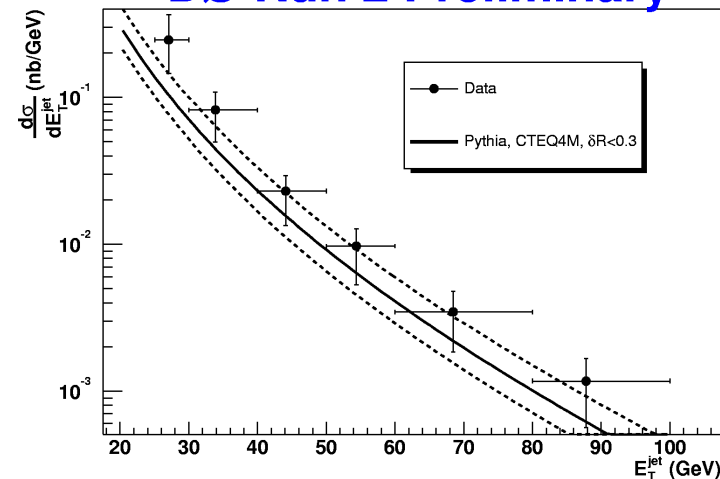
Theory uncertainty: vary renormalization/factorization scales (other sources smaller).
 → data at upper limits of theory prediction

No new b-jet cross section results submitted to ICHEP,
both experiments have analyses in progress.

CDF: 150 pb⁻¹, jets in central rapidity,
midpoint cone jets, 30 GeV < p_T < 210 GeV
b-tagging with secondary vertex tags



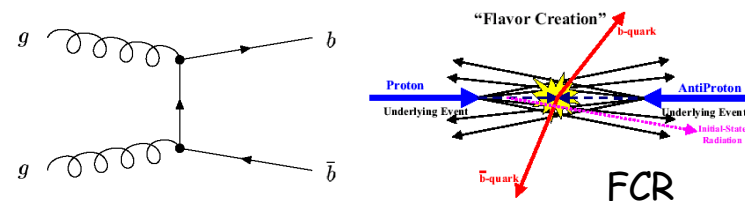
DØ Run 2 Preliminary



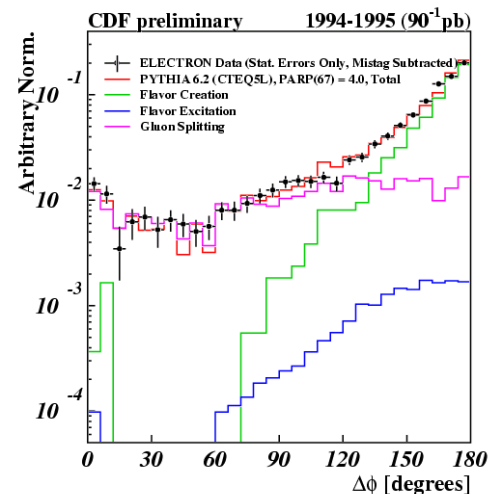
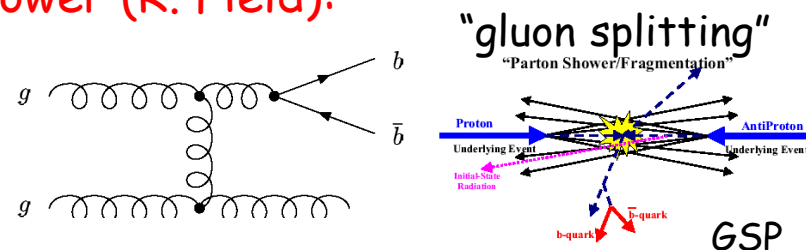
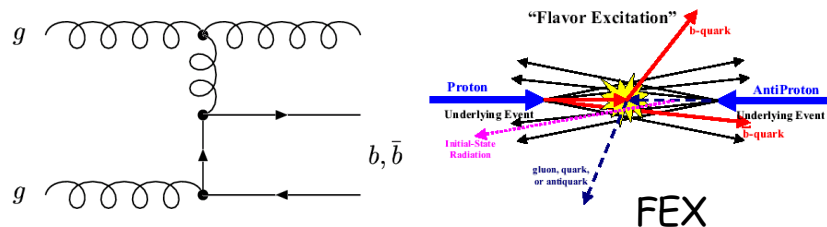
DØ, 3.4 pb⁻¹, muon+jets,
b-tagging using p_T of muon
relative to jet axis.

CDF and DØ are also looking at di-jet production with b-tagging:
study b-jet production mechanisms and di-jet mass distributions

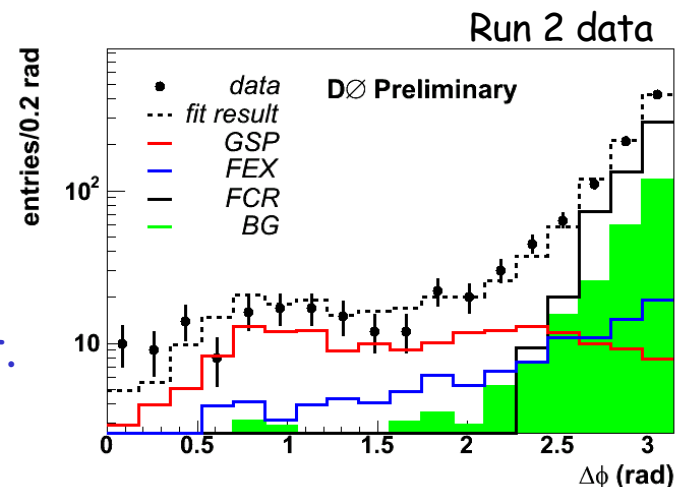
In the framework of LO generators like PYTHIA, Tevatron data cannot be described with only b - \bar{b} flavor creation.



Some NLO diagrams reflect different production mechanisms, not part of ME in PYTHIA, but part of initial/final state shower (R. Field):

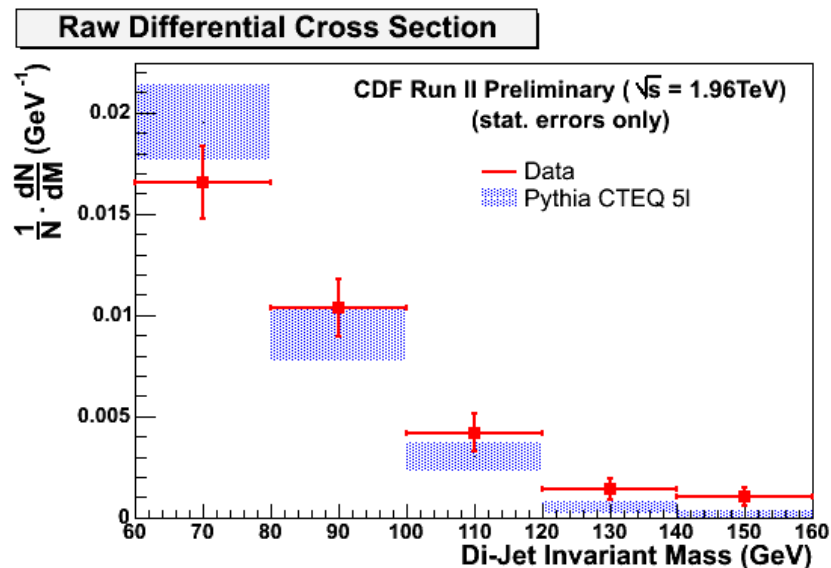
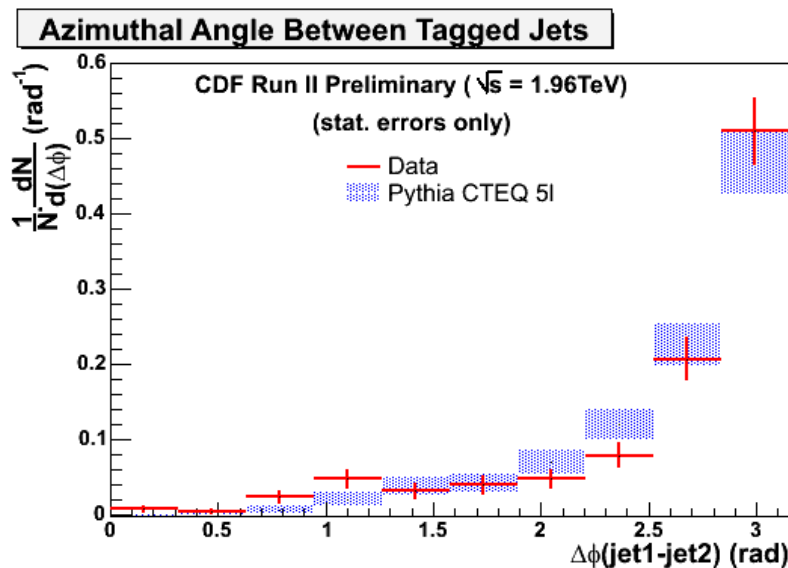
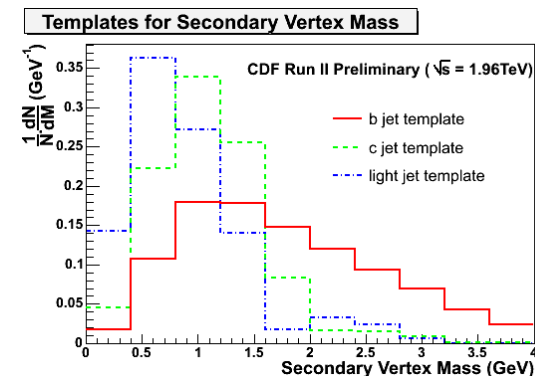
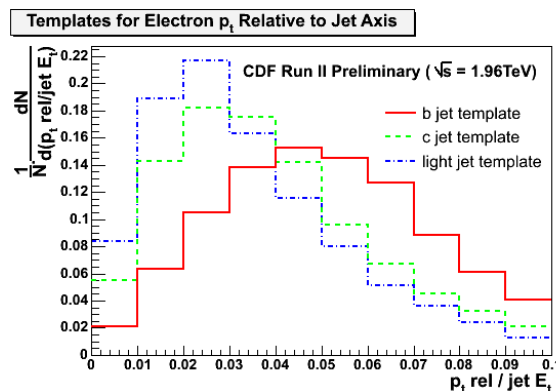


Disentangle components:
plot $\Delta\phi$ between b -tagged jets.
Compare to templates and fit.
Is tuning PYTHIA enough?



CDF: study b-bbar di-jet production at high p_T , $|\eta| < 1.2$

Tag b-quarks with secondary vertex tag, determine b-fractions by using additional soft electron tag, fit templates of p_T of electron relative to jet axis, and vertex mass.

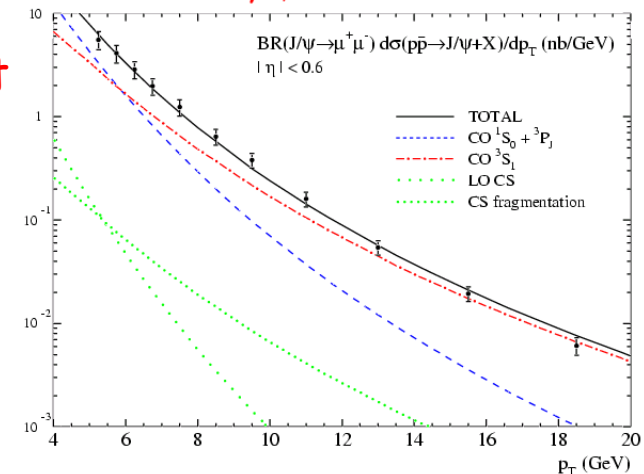


Prompt production of heavy quarkonium (J/ψ , ψ' , Y , ...) described by non-relativistic QCD (NRQCD).

Run 1 data has shown that color singlet component only (QQ state has quantum numbers of cc pair produced in hard scattering) is not sufficient. (by a factor 50 or so...)

Color octet component in NRQCD described by matrix elements that must be fit from data but are universal!
(CO OK: soft gluons take care of color flow)

CDF J/ψ Data, Run I

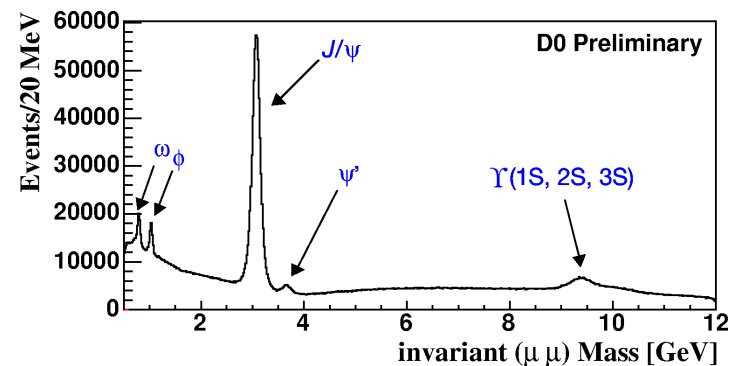
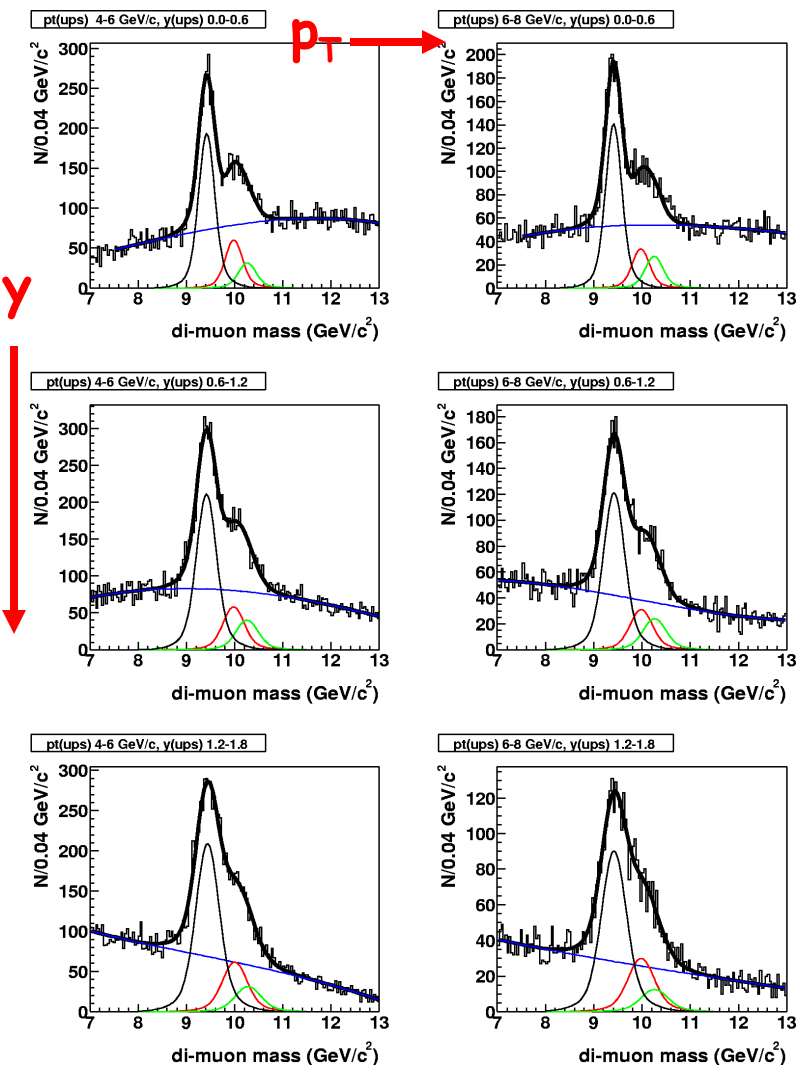


Alternative models: color evaporation model, soft color interaction model

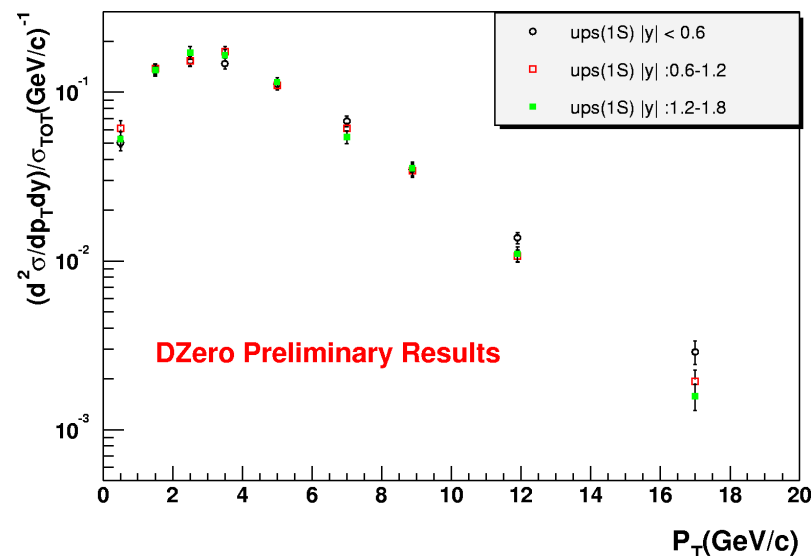
Interesting to study high p_T region and polarization

DO: 159 pb⁻¹ of data taken with dimuon trigger:

Fit $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ components:

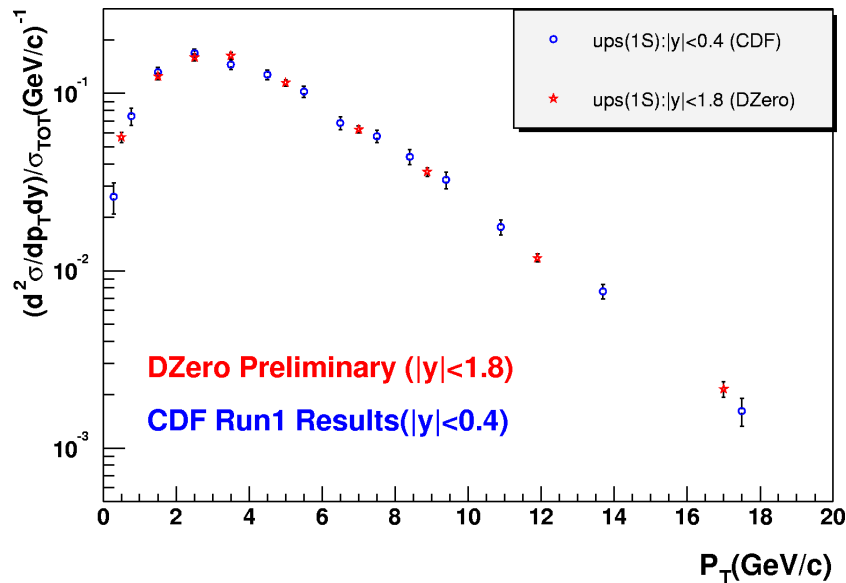


Extract $\Upsilon(1S)$ cross section:

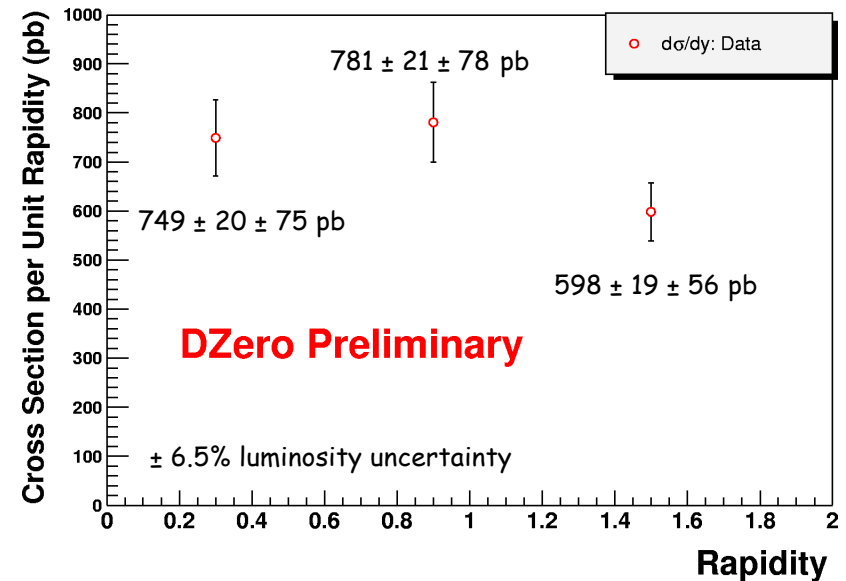


First measurement for forward rapidities: p_T spectrum varies only very little

Compare to CDF Run 1 result:



Cross section per unit of rapidity:
(includes $\text{Br}(Y \rightarrow \mu\mu)$)



$|y| < 1.8$: $695 \pm 12 \pm 65 \pm 45$ pb

CDF, $\sqrt{s} = 1.8$ TeV, $|y| < 0.4$: $d\sigma/dy \cdot \text{Br} = 680 \pm 15 \pm 18 \pm 26$ pb

DO, $\sqrt{s} = 1.96$ TeV, $|y| < 0.6$: $d\sigma/dy \cdot \text{Br} = 749 \pm 20 \pm 75 \pm 49$ pb

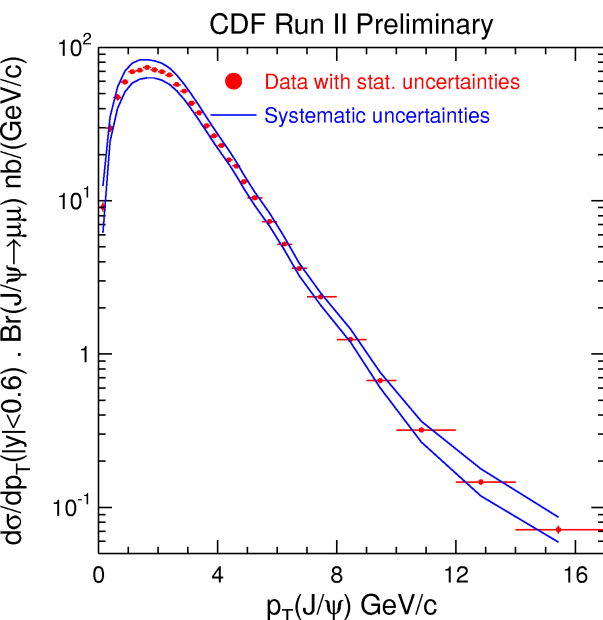
(PYTHIA predicts factor 1.11 between 1.96 and 1.8 TeV)

Polarization measurement is in progress...

Analogous: $J/\psi \rightarrow \mu\mu$

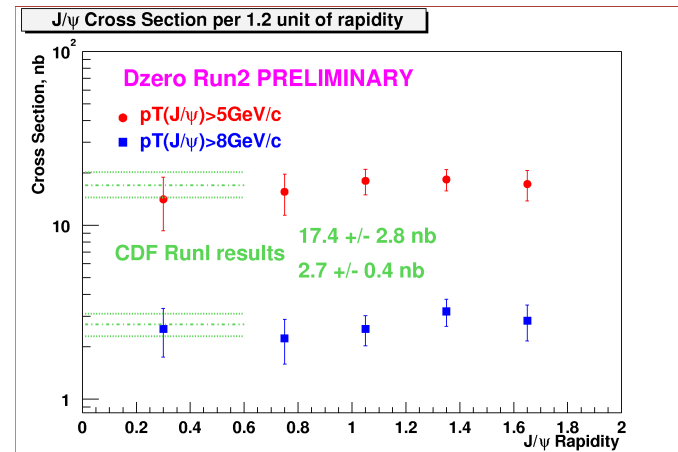
CDF: 39.7 pb^{-1}

J/ψ : $p_T > 1.25 \text{ GeV}$, $|y| < 0.6$

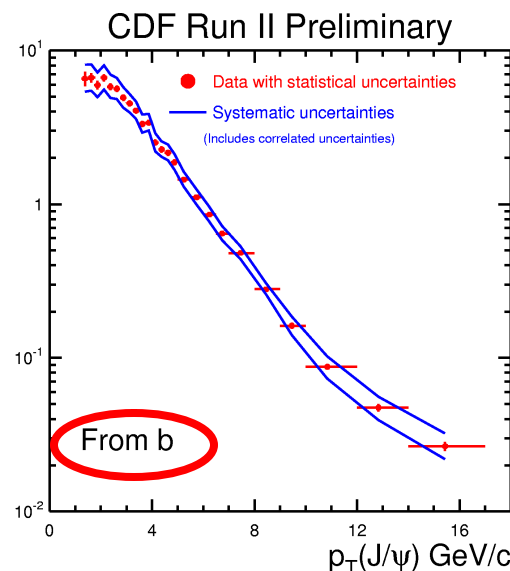
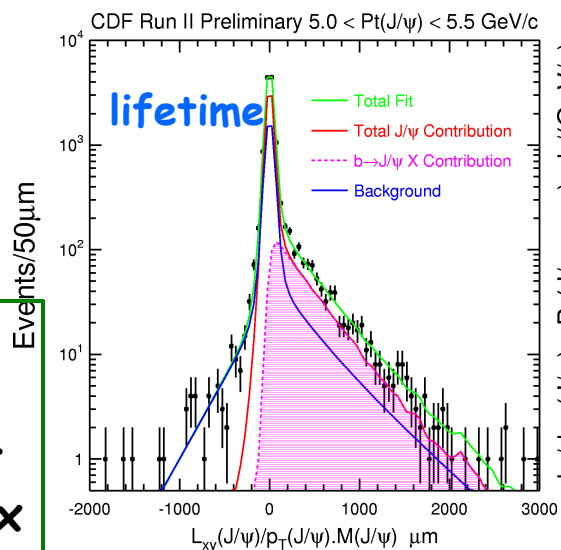


Depending on p_T , 10-40% of J/ψ are from b -decay.
Extract $B \rightarrow J/\psi X$ by looking at lifetime J/ψ production vertex

DO: 4.7 pb^{-1}
 J/ψ : $p_T > 5 \text{ GeV}$
 $|y| < 1.8$

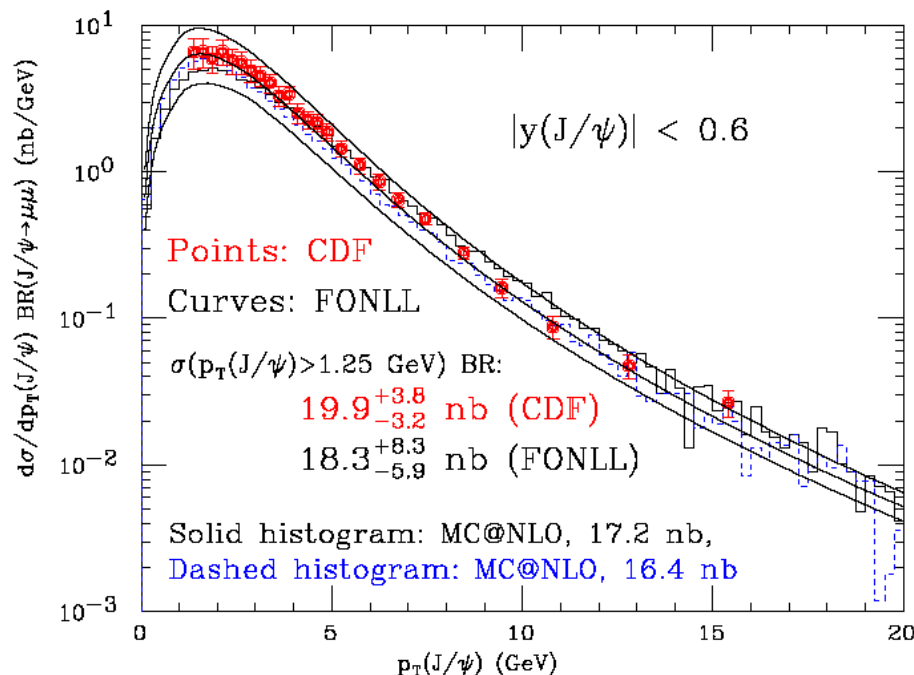
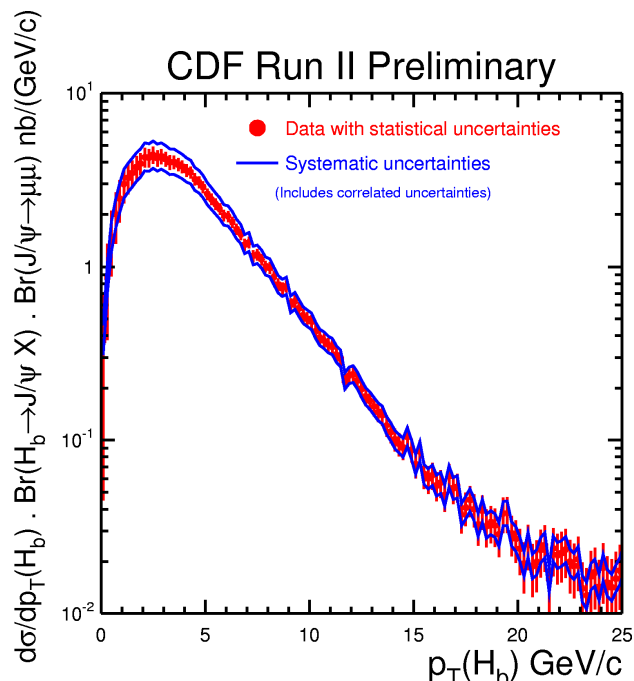


Nice idea: rather clean measurement,
can go down to $p_T(B) \sim 0$



CDF then uses MC unfolding to transform J/ψ p_T spectrum into a B hadron p_T spectrum:

Cacciari, Frixione, Mangano, Nason, Ridolfi have compared these results to FONLL and MC@NLO: (JHEP07 (2004) 033)



$$\sigma(J/\psi \text{ from } H_b) = 19.9 \pm 3.8 \text{ nb (within cuts)}$$

$$\sigma(H_b \rightarrow J/\psi, |y| < 0.6) = 24.5 \pm 4.7 \text{ nb}$$

$$\sigma(bX, |y| < 1.0) = 29.4 \pm 6.2 \mu\text{b}$$

Truly remarkable agreement!

(They note that agreement deteriorates when more and more corrections are done...
→ indication: manipulate data as little as poss.)

(Not covered: X(3872) production: separate talks
Pentaquark searches: negative results from CDF)

Charmed meson production measured: compatible with FONLL, although at the upper end of the predictions...

b-jet analyses in progress, including production mechanisms and di-jets

New upsilon production analysis, significantly extending rapidity coverage, in agreement with earlier results.

b-hadron production measurement extracted from J/ψ production, in very good agreement with FONLL and MC@NLO.

→ the Tevatron b quark "excess" is understood, and not an excess.

However: lots more data coming: 400 pb⁻¹ in the bag, 1.5 fb⁻¹ summer 2006...
Statistical errors will be negligible, systematics will dominate

MC@NLO is a great tool. But will theory keep up with Tevatron luminosity?
NNLO beyond current capability. Resummation of low x effects difficult...